GRANULOMETRIC AND THERMOPHYSICAL STUDY OF EARTH USED AS A STRUCTURAL MATERIAL IN NORTHERN MOROCCO AND APPLICATION OF A GENERAL IDENTIFICATION METHOD TO THE STUDIED PARAMETERS [1]

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ABSTRACT

The study of the thermal behaviour of a building material constitutes an important element to be taken into account in a building.

The thermophysical properties in which we are interested in this study are the thermal conductivity (λ) and the thermal diffusivity (a), since they contribute to a better understanding of the thermal behaviour of insulation and construction materials.

We are particularly interested in earth extracted from various areas from northern Morocco where the dominant technique is Adobe. The study was carried out on samples taken in a normal state.

Moisture influence was highlighted by a study of the thermal conductivity and the thermal diffusivity of non-stabilized samples versus their volume water content.

A general method of identification was used which is based on the resulting time evolution of the experimental temperature on the non-irradiated surface of the sample.

KEY WORDS**:** Construction materials ; earth; granulometric ; measurements and identification ; thermal conductivity ; thermal diffusivity ; thermal loss coefficients.

1. INTRODUCTION

The resumption of construction using local materials has been required owing to the economic, energy and accommodation crises, which have requested alternative materials.

In the sector of building, the solution was to increase the use of local materials and to decrease the use of large energy consuming and manufactured materials.

This work enters within the framework of the study of thermophysical properties of local building materials. It follows a very interesting study that was already carried out on plaster, cork and hollow bricks [1].

We are interested in earth, which by its abundance and the multiple possibilities it offers for construction is an excellent local material.

Earth is extracted from various sites from the northern area of Morocco, where the dominant construction technique is adobe.

The adobe brick is a performed modular masonry unit of sun-dried mud, which can be either stabilized, or not.

A primary study of the thermal properties was carried out on samples taken in a normal state, or a state where they are permanently exposed to the air under standard conditions of temperature and moisture allowing us to classify the studied materials.

The study of the influence of water content on the apparent thermal diffusivity highlighted the thermal behaviour of earth in presence of water.

We have thereafter used a general method of identification of the thermophysical parameters of material based on the time evolution of the experimental temperature on the non-irradiated surface of a sample. It’s concerned by reproducing the phenomenon theoretically. To this end, a numerical simulation, taking into account the experimental conditions, allows to judge the validity of the model by a comparative study of numerical and recorded experimental results. The poorly known parameters intervening in the equations of the model are then given with the help of the parametric identification. The mathematical model used is based on the thermal networks method.

This method of identification, is based on the general principle of identification using a method called the model method [2], and which consists in minimizing a criterion function " J " which is a quadratic form of the difference of temperatures obtained by simulation of the model and those recorded experimentally

Regarding the experimental measurements, in steady regime for the apparent thermal conductivity and in the dynamic regime for the apparent thermal diffusivity, we have used the “method of Boxes”.

2. PRINCIPLE OF MEASUREMENT OF THE THERMOPHYSICAL PROPERTIES

2.1. Thermal conductivity

The measuring device of the thermal conductivity, is based on “the method of Boxes” developed in the laboratory of Thermal and Solar Studies of the Claude Bernard University in France [1,3,4].

The method of Boxes requires parallelepiped sample forms. Sizes are $(27\times 27\times e).10^{-6}$ m^3 where the thickness e varies from 1 to 6 cm. The sample is placed, as shown in Fig.1, between a cold isothermal capacity and a heat source of a constant flow.

Once the steady state is established, thermal conductivity is then given by:

$$\lambda_a = \frac{e}{S\Delta T}(q + C\Delta T') \qquad (1)$$

with:

C : thermal coefficient of deperdition (W . °C^{-1})

e : thickness of the sample (m)

q : unidirectional heat flow $(W . m^{-2})$

S : surface of the sample (m^2)

T : Temperature (°C)

λ : Thermal conductivity $(w . m^{-1} \cdot °C^{-1})$

ΔT : Variation in temperature between cold and heated faces of the sample (°C)

$\Delta T'$: Variation in temperature between external and internal environments (°C)

$_a$: apparent

2.2. Thermal diffusivity

The device of measurement is the same one as that used for the measurement of thermal conductivity [1,3,4].

The sample, as shown in Fig. 2, is placed between a hot Box whose internal wall surfaces are reflective, and an isothermal capacity A. It receives a thermal impulse of short duration and constant flow (1000 watt) .

The analysis of the experimental thermogram recorded on the non-irradiated face of the sample makes possible to reach the apparent thermal diffusivity by using already existing examination techniques [6].

3. GRANULOMETRIC STUDY OF SAMPLES

The various types of earth studied in this article, are indicated by the names of the areas from where they were taken. A fast examination of these kinds of earth showed that they have different colours and grain sizes.

Before making bricks, the identification of the studied earth proves to be necessary. Indeed, the earth must be a mixture of various elements with an optional granularity. These elements are: Gravels, sands, silts and clays [5].

According to the curve of Fig. 3, we can conclude that:

- Soils taken from “Larache, Tangier, Aouamra and Ksar al kebir” sites are fine and contain a great percent of silts and fine sands.

- Soils taken from ' Al hoceima and Tetouan' sites represent a significant percentage of sand, also the maximum diameter is definitely higher compared to other soils.

The study was carried out on samples taken in a normal state or a state where they are permanently exposed to the air under natural conditions of temperature, pressure and moisture, so their water content are then not null.

The characteristics of the various samples are presented in table I.

3.2. Results and interpretations

The results of the thermophysical properties measurements, in a normal state, are presented in table I.

Regarding the thermal conductivity, the material of Al hoceima site followed by the material of Tetouan site is the most insulating. They contain, as shown in the grading curve, a great percentage of coarse aggregates. This can be explained by the fact that the existence of coarse aggregates supports the infiltration of the air, which is a good insulating material.

The materials of Al hoceima, Tetouan and Ksar Al Kebir sites are the least diffusing materials.

4. INFLUENCE OF MOISTURE ON THERMAL DIFFUSISVITY

Considering the importance of the climatic conditions, and notably the moisture, on the thermal behaviour of earth, a study of the influence of moisture on the thermal diffusivity of the different samples has been carried out.

4.1. Results of measurement

The study of the thermal diffusivity according to the water content could not be made for high water content since the sample erodes quickly in contact with the least quantity of water and a higher water content can cause the disintegration of the samples. Indeed, by humidifying materials by successive watering, we note that:

The samples of the Aouamra and Larache sites are the strongest considering their resistance to water or erosion under the action of water. The Ksar Al kebir sample is subjected to sudden swellings under the action of water. As for the sample of Tangier, the surface is exhausted quickly. These two causes made very difficult the study of the thermal behaviour of the thermal diffusivity according to the water content. This sensitivity to moisture is justified by the fact that the Ksar al Kebir material presents a very large limono-argillaceous fraction of about 54.28%. So then when the water content of the material increases, the thickness of the absorbed water films and the apparent total volume of brick increases. For the brick of Tangier site, the percentage of the limono-argillaceous fraction which ensures the cohesion of earth is weak and is about 26.37%. Consequently, the material is exhausted in the presence of water, these earths have a disadvantage of not resisting to water, but this can be avoided by stabilization.

The sample of Al hoceima site is exhausted quickly. This made very difficult the study of the variation of thermal diffusivity according to the water content. This soil has the disadvantage of not resisting to water damage, but it can also be avoided by stabilization.

The summary of the results of thermal diffusivity measurement according to water content is given in table II.

As regards Aouamra material, diffusivity increases quickly for low volume water content W_v <2.6% and tends to be stabilized for values of water content higher than 6.9%.

For Larache material, diffusivity increases quickly for water contents W_v<4% and tends to be stabilized for water contents ranging from 4% to 5.5% and again when they are higher than 8%.

5. METHOD OF IDENTIFICATION

5.1. Position of the problem

The calculation of the thermal diffusivity by the mathematical models, which are based on the thermal networks method, uses one or more physical parameters which are not well known. we are interested in the following parameters:

- a: thermal diffusivity.
- h_o : coefficient of convection losses in position x=0 (irradiated surface of the sample).
- h_e : coefficient of convection losses in position x = e (non irradiated surface of the sample).

h_o and h_e cannot be calculated theoretically with accuracy the fact that explains, in this case, the relatively important gap between the theoretical temperature, resulting from the model, and the experimental temperature.

In order that the equations of the model gives the closest solution possible to the real behaviour of the process, we have used the method of parametric identification [1,2], that is valid whatever is the type of the poorly known model.

This procedure of identification is based on the general principle of the identification using the method of model [2]. The non irradiated face temperature response of the sample is given by [4]:

$$T(e,p)=\frac{Q(0,p)}{c} \qquad (2)$$

$$c=\lambda SK\ sh(xK) \quad ; \quad K=\sqrt{\frac{p}{a}}$$

With :

p : Laplace variable.

Q : flux Laplace transform.

From the thermogram of the non irradiated face of the sample, we seek to approach the best possible the analytical expression of the model T(x,t) to the experimental curve Texp(x,t) obtained on the recorder, by the functional J " criterion of the least squares" given by :

$$J(a,h_e,h_0)=\sum_{i=1}^{n}\left[\frac{T_{\exp}(x,t_i)-T(x,t_i)}{T_{\exp}(x,t_i)}\right]^2 \qquad (3)$$

The parameter of identification is then the thermal diffusivity a.

The initialisation of the identification procedure is chosen by giving to these parameters values calculated from:

- The model of deprivation of Yezou for the thermal diffusivity a

- The empirical formulas of the literature for h_o and h_e.

5.2. Results and interpretations

The results of identification of the models with only one, two and three parameters, are given on Table. III, for the six types of earth: Aouamra, Larache, Al Hoceima, ksar al kebir, Tangier and Tetouan. It allows us to analyse all the values obtained in each case and for each material.

When the number of parameters to be identified increases, we obtain the following results:

- The value of the criterion J decreases.

- The relative error ($\Delta a / a$) between the value of the thermal diffusivity obtained after identification and the value given by the method of deprivation [6] decreases while going from the one parameter case to the three parameters case, trough the two parameters case.

From these results, we can say that the mathematical model used represents correctly the real evolution of the temperature response of the non irradiated face of the studied samples.

6. CONFRONTATION WITH THE IDENTIFICATION METHOD

6.1 Comparison of the results

Results obtained from the model of deprivation of Yezou [6] are compared on Fig. 4 and Fig. 5, with those of the identification method.

Results of measurement obtained using the model of deprivation are in a good agreement with those obtained by the method of identification. For the Aouamra material, experimental results are very close to the results deduced from the method of identification The average relative discrepancy between these results does not exceed 3%. As for Larache material, the experimental results are well reproduced by the model for the weak water contents, but present an average discrepancy of 5% for water contents superior to 4%.

Errors on measurements of thermal diffusivity which are 9% are not taken into account.

7. CONCLUSION

The results obtained lead to the following conclusions:

- We cannot confirm the insulating power of materials, but this does not prevent us from comparing them according to their characteristics. Indeed, if a choice of a material has to be made by taking into account their thermophysical characteristics and if in addition we want to take into account other criteria based on their behaviour with respect to water, we can say that the appropriated earth of Aouamra and Larache responds better to this requirement.

The mathematical model used represents correctly the real evolution of the temperature response on the non irradiated face of the studied samples

Moisture affects the thermal diffusivity of the material. Measured evolutions of thermal diffusivity according to the water content are important and very variable from an earth to another. However, the water contents are relatively weak.

Experimental measurements based on the method of deprivation of Yezou, can be reproduced by the method of identification.

In terms of prospects, it seems to us important to continue the study of this material under two angles :

- The effect of the stabilization of the material with respect to the cement and to the straw on its characteristics. This study will allow us to make a choice of the most suitable stabilizing material.
- The study of the mechanical behaviour of the material.

These studies will allow us to find the conditions of use of the material as an insulator and a carrier.

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Table I. Characteristics of the studied samples

Designation	e (cm)	ρ normal (Kg.m^{-3}) (ρ = Density)	$T_{average}$ (°C)	colour	λ (w.m^{-1}.°c^{-1})	a (.10^{-7}.m^{2}.·s^{-1})
Aouamra	4.7	1673	19.8	Grey	0.806	6.580
Ksar al kebir	4.4	1956	20.5	Grey	0.933	5.600
Al hoceima	4.9	1647	19.9	Brown	0.530	2.886
Larache	4.4	1829	19.5	Grey	0.980	7.195
Tanger	4	1697	21.8	Red brick	0.844	6.299
Tétouan	4.5	1879	20.1	Grey	0.680	3.940

Table II. Variation of thermal diffusivity versus the volume water content

Designation							
Aouamra	W_v(%)	0	2.509	5.687	6.917	10.55	11.995
	a_{yezou} ($.10^{-7} m^2.s^{-1}$)	5.40	6.58	6.659	6.699	7.6208	7.904
Al hoceima	W_v(%)	0	4.323	13.64			
	a_{yezou} ($.10^{-7} m^2.s^{-1}$)	2.856	2.886	4.574			
Larache	W_v(%)	0	3.436	4.721	7.36	9.604	
	a_{yezou} ($.10^{-7} m^2.s^{-1}$)	5.644	7.195	7.201	8.64	9.01	
Tétouan	W_v(%)	0	5.34	7.751			
	a_{yezou} ($.10^{-7} m^2.s^{-1}$)	3.811	3.902	3.94			

Table III. Summary of results

Designation	a_{yezou} $(.10^{-7}m^2.s^{-1})$	Identification of:	Jo	$a_{identification}$ $(.10^{-7}m^2.s^{-1})$	$\Delta a/a$
	6.58	a	1.19	5.46	0.17
Aouamra	6.58	a and h_e	$6.00\ 10^{-1}$	6.44	0.021
	6.58	a, h_e and h_o	$5.99\ 10^{-1}$	6.44	0.021
	5.6	a	2.009	3.374	0.397
Ksar Al kebir	5.6	a and h_e	$7.466\ 10^{-1}$	4.70	0.160
	5.6	a, h_e and h_o	$7.460\ 10^{-1}$	4.71	0.158
	2.886	a	1.327	2.514	0.128
Al Hoceima	2.886	a and h_e	$9.53\ 10^{-1}$	2.787	0.034
	2.886	a, h_e and h_o	$9.53\ 10^{-1}$	2.789	0.033
	7.195	a	1.20	6.434	0.105
Larache	7.195	a and h_e	$7.404\ 10^{-1}$	7.498	0.042
	7.195	a, h_e and h_o	$7.39\ 10^{-1}$	7.47	0.038
	6.299	a	2.2	3.920	0.37
Tanger	6.299	a and h_e	$9.8\ 10^{-1}$	5.560	0.117
	6.299	a, h_e and h_o	$9.8\ 10^{-1}$	5.644	0.104
	3.94	a	1.533	3.03	0.230
Tetouan	3.94	a and h_e	$5.45\ 10^{-1}$	3.83	0.028
	3.94	a, h_e and h_o	$5.45\ 10^{-1}$	3.817	0.031

FIGURE CAPTIONS

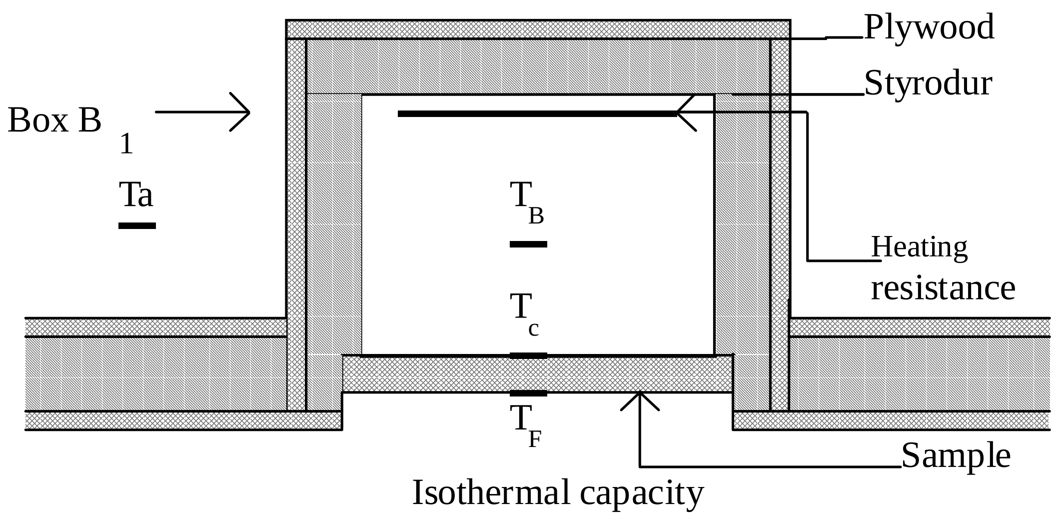
Fig. 1. Measuring box of the thermal conductivity and position of the probes.

Fig. 2. Thermal diffusivity measuring box.

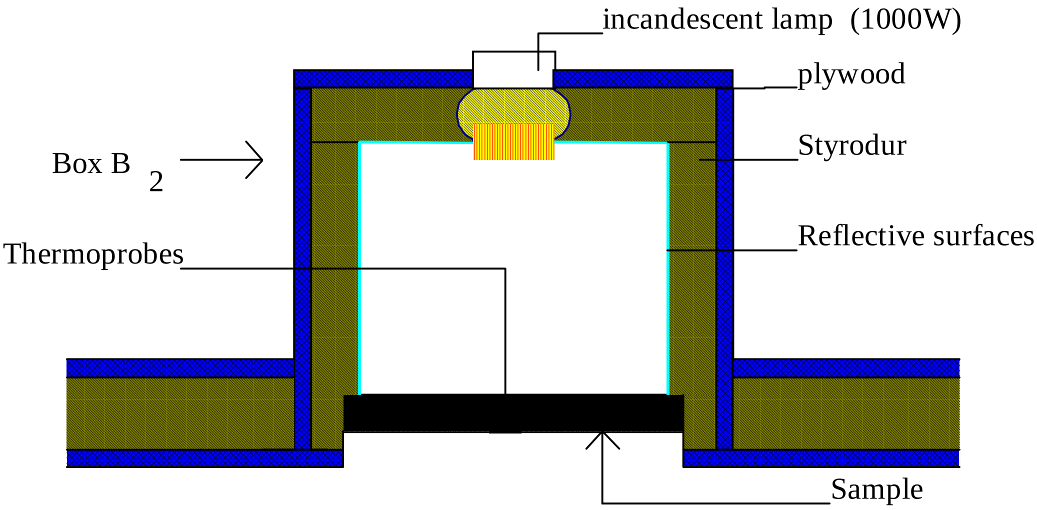
Fig. 3. Granulometric and sedimentometric curves of the six kinds of earth.

Fig. 4 . Thermal diffusivity versus water volume content for the Aouamra material.

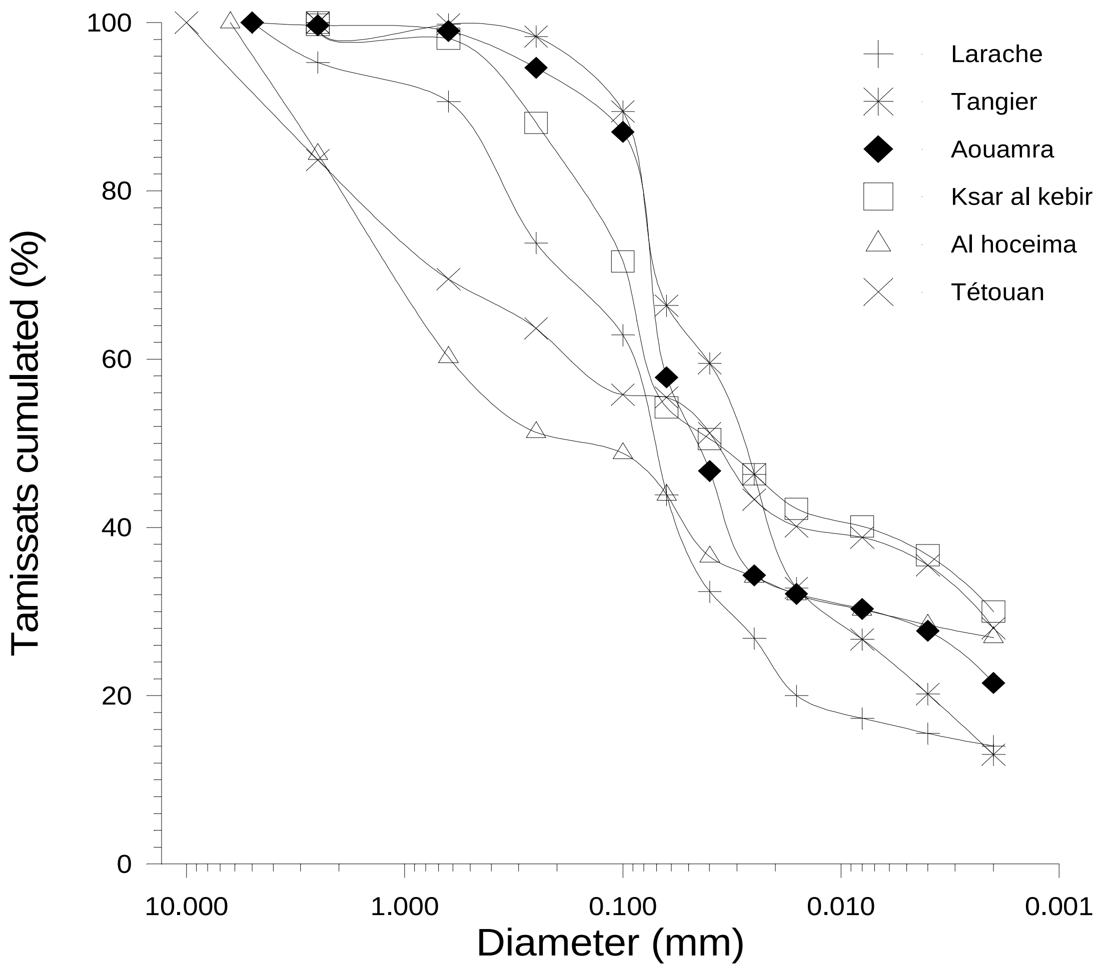
Fig. 5 . Thermal diffusivity versus water volume content for the Larache material.



Plywood
Styrodur
Box B 1
Ta
T_B
Heating resistance
T_c
T_F
Sample
Isothermal capacity



isothermal Capacity


100
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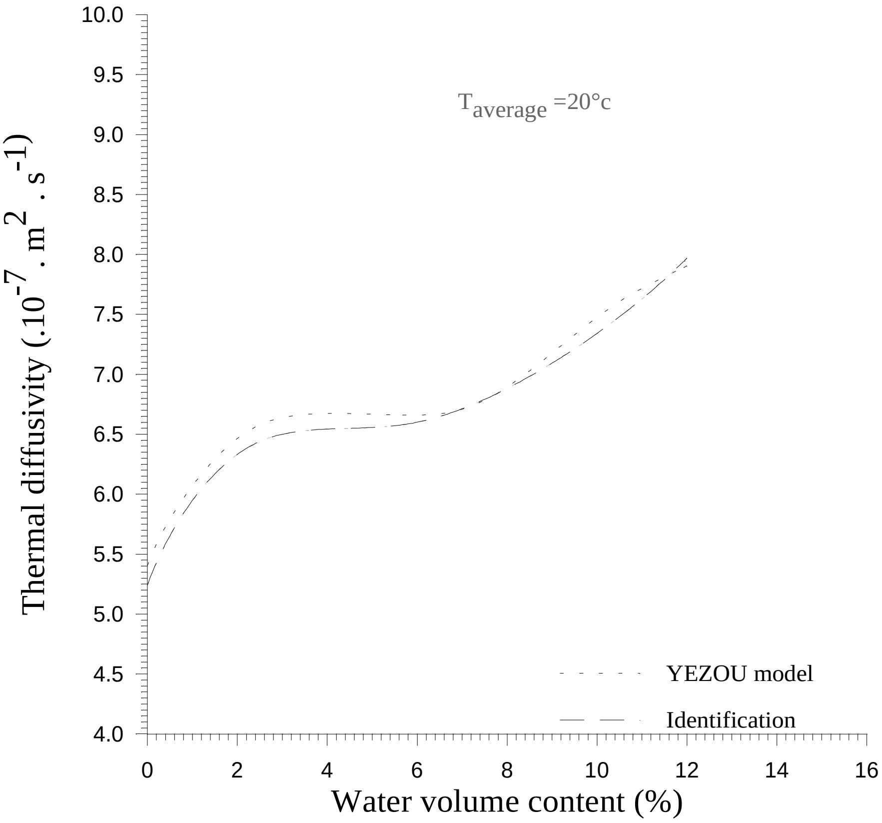
Diameter (mm)
Tamissats cumulated (%)
Larache
Tangier
Aouamra
Ksar al kebir
Al hoceima
Tétouan



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Thermal diffusivity (.10^{-7} . m^2 . s^{-1})
T$_{average}$ =20°c
YEZOU model
Identification
0
2
4
6
8
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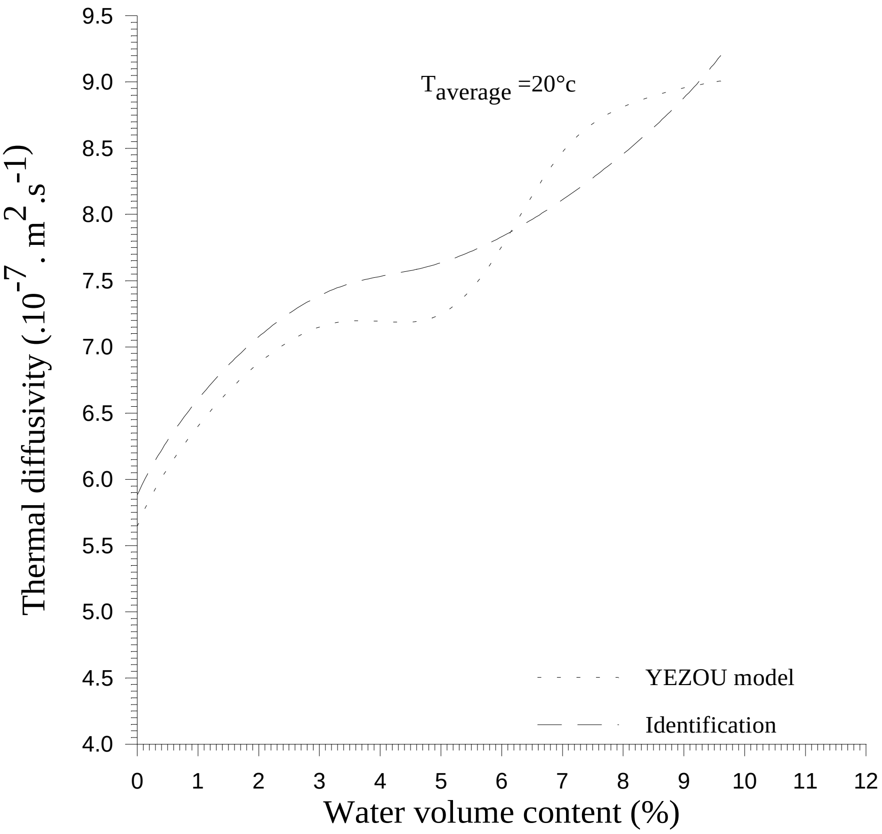
12
14
16
Water volume content (%)



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Thermal diffusivity (.10-7 . m2.s-1)
T average =20°c
YEZOU model
Identification
0 1 2 3 4 5 6 7 8 9 10 11 12
Water volume content (%)